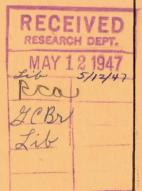
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1230



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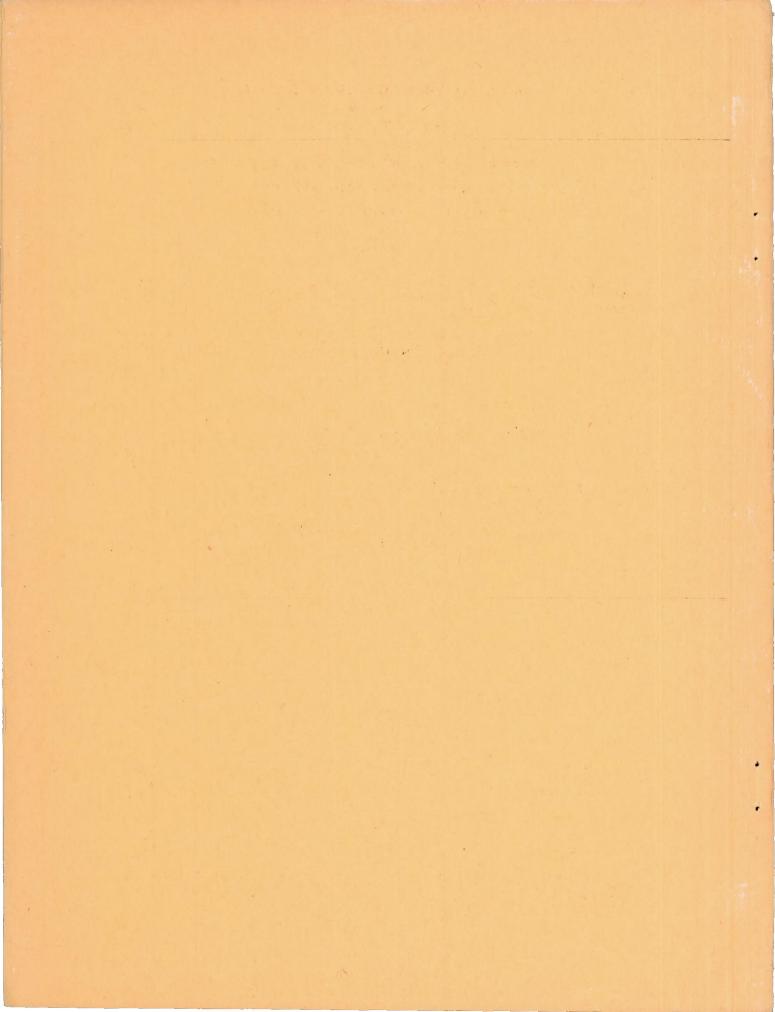
LOW-CARBON N-155 ALLOY

By

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Washington April 1947



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A METALLURGICAL INVESTIGATION OF LARGE FORGED DISCS

OF LOW-CARBON N-155 ALLOY

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SUMMARY

This report in one of a series on a cooperative research investigation undertaken to ascertain the properties of the better wrought heat-resisting alloys in the form of large discs required for gas turbine rotors.

The properties of large discs of Low-Carbon N-155 alloy in both the asforged and water-quenched and aged conditions have been determined by means of stress-rupture and creep tests for time periods up to about 2000 hours at 1200°, 1350°, and 1500° F. Short-time tensile test, impact test, and time-total deformation characteristics are included.

The following principal results were obtained from the 14 3/4-inch-diameter by 4 3/8-inch-thick discs:

			Water quenched and				
		As-forged Disc 1L	Aged at 1350° F Disc 2R	Aged at 1500° F Disc 2L			
Α.	Brinell hardness range on center plane at rim on center plane at center	210 180	200 174	210 200			
В.	Offset yield strengths		THE STATE OF THE S				
	0.2-percent offset yield strength at:	311	<u>(psi)</u>				
	room temperature 1200° F 1350° F	67,800 46,250 40,020	56,420 31,100 29,100	62,150 39,320 40,650			
	1500° F	35,600	34,500	33,850			
c.	Rupture-test characteristics (Stress to cause rupture in indicated time periods)		(psi)				
	1200° F rupture strength 10 hr 100 hr 1000 hr	55,000 46,000 38,500	48,000 41,500 36,000	55,000 44,000 35,000			
	1350° F rupture strength 10 hr 100 hr 1000 hr	39,000 28,000 20,000	34,500 28,000 23,000	38,000 28,000 21,000			
	1500° F rupture strength 10 hr 100 hr 1000 hr	16,500 11,800	23,700 18,500 13,000	18,000 12,200			

The elongations and reductions of area of the fractured rupture-test specimens were quite good, and increased rupture time did not produce a significant change in ductility.

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D. Total-deformation characteristics under stress

The data for the three discs tested are too voluminous to repeat in this summary. Briefly, the as-forged disc was generally superior to the heat-treated and aged discs at 1200° F. At 1350° F the superiority of the as-forged disc was lessened, and at the lower stresses disappeared. At 1500° F the heat-treated and aged discs showed increasing superiority over the as-forged disc particularly at the lower stresses which produced low rates of deformation and long life.

Aging at 1350° F, rather than at 1500° F, produced higher strengths in tests at 1350° F, and some beneficial effects from aging at 1350° F were still evident in tests at 1500° F for the test duration used in this investigation.

E. Uniformity

The properties of the discs were quite uniform considering the size of the forgings and the characteristics of the alloy.

F. Stability

The impact strength and ductility decreased after creep testing at 1200°, 1350°, and 1500° F. The strength values from tensile tests increased after creep testing at 1200° and 1350° F, and either changed very little or were slightly lowered after creep testing at 1500° F.

INTRODUCTION

This report presents the results of a study of the room-temperature, 1200°, 1350°, and 1500° F properties of three large forged discs of Low-Carbon N-155 alloy. One of the discs was tested in the as-forged condition, and the other two discs were solution treated and aged. The primary purpose of this study was to determine the level of properties exhibited by this alloy in the form of large forgings of the type required for rotor wheels in gas turbines and to determine the relative properties of as-forged and heat-treated alloy discs. The discs investigated and herein reported were several from a series now under study. The results obtained previously from similar investigations on 19-9DL, CSA, and Low-Carbon N-155 discs have been published as references 1, 2, and 3.

This work is being carried out as part of two correlated programs of research on alloys for gas-turbine applications in progress in this country. The National Advisory Committee for Aeronautics is sponsoring work directed toward the development of improved high-temperature alloys for gas turbines used in aircraft power plants. A concurrent program, formerly sponsored by the National Defense Research Committee, Office of Scientific Research and Development, and now sponsored by the Office of Naval Research, Navy Department, is being directed to the development of alloys for gas-turbine applications in general, and in particular to both ship and aircraft propulsion. The work herein was performed with the financial assistance of the National Advisory Committee for Aeronautics, the National Defense Research Committee, and the U. S. Navy.

This report is based on the joint effort of the three research programs and is being distributed by both the NACA and the Navy. The investigation of these discs for the NACA was conducted at the Department of Engineering Research of the University of Michigan, for the U. S. Navy by Battelle Memorial Institute, and for NDRC Project NRC-8 by some of the following 12 cooperating laboratories:

American Brake Shoe and Foundry Company Battelle Memorial Institute Crane Company Federal Shipbuilding and Dry Dock Company Lunkenheimer Company Massachusetts Institute of Technology The Midvale Company University of Michigan National Bureau of Standards Research Laboratory, Westinghouse Electric and Manufacturing Company

TEST MATERIALS

The available information concerning the discs may be summarized as follows:

Manufacturer:

Crucible Steel Company of America

Heat Number:

1X2232

Chemical Composition:

The chemical composition was reported to be the following percentages by the manufacturer:

C Mm Si Cr Ni Co Mo W Cb N 0.07 1.68 0.60 20.80 20.60 20.07 2.94 2.67 1.05 0.125

Fabrication Procedure:

Three 9-inch billets from a 2000-pound induction furnace heat were direct upset to produce discs 14 3/4 inches in diameter by 4 3/8 inches in thickness. The finishing temperature was about 1500° F. The left and right halves of each disc were heat treated as follows:

	Solution treatment	Aging
Disc 1L	None	Tested in the as-forged condition.
Disc 1R	None	24 hours at 1500° F
Disc 2L	2200° F, water quenched	24 hours at 1500° F
Disc 2R	2200° F, water quenched	24 hours at 1350° F
Disc 3L	2250° F, water quenched, reheated to 1500° F and reduced 3 percent, finishing temperature about 1200° F	24 hours at 1500° F

Sampling:

The code number assigned to the discs was NR-66E. Figure 1 shows the location of the samples cut from the halves of the various discs and the code system identifying the coupons. The letters refer to locations on the flat faces of the discs, and the numerals refer to the locations through the thickness of the discs.

EXPERIMENTAL PROCEDURE

The investigation was designed to provide four types of information: (1) the physical properties at room temperature, 1200°, 1350°, and 1500° F which can be expected in large forgings of the Low-Carbon N-155 analysis; (2) the effect of fabrication and heat treatment on these physical properties; (3) the variation in properties which might be present in various locations in such large forgings; and (4) the change in properties resulting from exposure to elevated temperatures under stress for prolonged time periods.

The physical-property data obtained for these large forged discs of Low-Carbon N-155 alloy included short-time tensile properties, impact strengths, rupture-test characteristics, and design curves of stress against time for total deformations of 0.1, 0.2, 0.5, and 1.0 percent at 1200°, 1350°, and 1500° F. The time-deformation data were obtained from time-deformation curves from both stress-rupture and creep tests.

The uniformity of the disc materials was checked by means of a hardness survey and by tensile and rupture tests on coupons from representative locations throughout the discs. Hardness, tensile, and impact tests and metallographic examinations on specimens after completion of the tests were used to estimate the stability of the material during prolonged exposure to temperature and stress.

The testing procedures used for the short-time tension, stress-rupture, and creep tests were in accordance with the provisions of the A.S.T.M. Recommended Practices E21-43 and E22-41.

RESULTS

The data obtained are compiled as a series of tables and figures, with the principal results from the three discs 1L, 2L, and 2R, on which most of the work was done, summarized in figures 2 to 4. The source of the data (NACA, NDRC, or Navy) is indicated in the tables.

Hardness Survey

The Brinell hardness of material cut from the discs with the five different processing and heat treatments ranged from about 165 to 235. (See fig. 5.) The hardness generally increased from the center to the rim of the disc.

The most uniform and highest over-all hardness was shown by disc 3L which was hot-cold worked after solution heat treatment. A slightly higher hardness was shown at the rim of the as-forged disc (1R) which was subsequently aged 24 hours at 1500° F after forging. The hardness of the as-forged disc which was not aged (1L) was uniformly lower than the as-forged and aged disc (1R). The hardness of the solution-treated disc aged 24 hours at 1500° F (2L) was quite uniform and was similar in magnitude to the as-forged or hot-cold worked discs (1L, 1R, and 3L). The hardness measured for disc 2R indicated that the aging for 24 hours at 1350° F as compared with 1500° F aging did not produce the maximum hardness except at the rim location where more working is accomplished in the direct-upset forging of discs from billets. It is considered that the hardness variations from center to rim of the discs were quite small, considering the size of the discs and the difficulties of forging of this highly alloyed material.

The hardness of the NR-66D disc (reference 2), which was manufactured by Universal Cyclops Steel Corporation and tested as forged and stress relieved for 2 hours at 1200° F, varied from 195 at the center to about 235 Brinell hardness at the rim of the disc on the center plane. This is very similar to the variation in hardness obtained on disc NR-66E-1R.

5.

Short-Time Tensile Properties

The results of the short-time tensile tests at room temperature, 1200°, 1350°, and 1500° F are shown in table I. By using 1/4-inch-diameter test specimens in the room-temperature tension tests, sufficient material was available to compare the properties of the surface and interior material. The data showed slightly higher strengths for the material taken near the surface of the discs and also a slight superiority for material near the rim, as compared with the center of the discs.

In the tests at 1200° F surface test bars showed slightly higher properties than interior test bars. Comparing the three discs tested, the asforged disc 1L showed higher strengths than the solution-treated and aged discs 2L and 2R at both room temperature and at 1200° F, but at 1350° and 1500° F superiority of the as-forged disc was shown only by the yield strengths and not by the tensile strength. The solution-treated disc aged at 1500° F was considerably stronger at room temperature and at 1200° F than the disc aged at 1350° F. The superiority produced by the 1500° F aging was considerably reduced when tested at 1350° F, and at 1500° F the two materials were quite similar in strength.

Charpy Impact Resistance

Charpy impact resistance ("V" notch) was determined on specimens from the three discs 1L, 2L, and 2R. Data are shown in table II and figures 2 to 4 from tests at room temperature, 1200°, 1350°, and 1500° F after holding at temperature for a time period sufficiently long to ensure a uniform temperature in the specimens.

The Charpy impact resistance at room temperature was lowest for the disc 2L which was water quenched and aged at 1500° F, with values of 4 to 8 footpounds. Aging at 1350° F, after solution treatment, as for disc 2R, produced considerably higher room-temperature impact resistance ranging from 20 to 43 foot-pounds. Similar impact resistance was shown by the as-forged disc (1L). For all three disc materials, tests at temperatures of 1200°, 1350°, and 1500° F produced considerably higher impact values than were obtained at room temperature.

Rupture-Test Characteristics

The stress-rupture data for the tests at 1200°, 1350°, and 1500° F are shown in table III, and the rupture strengths obtained from the stress-rupture time curves in figure 6 are summarized in table IV. All specimens tested were radial specimens, located as indicated in table III.

All five discs were tested at 1200° F and 100-hour and 1000-hour rupture strengths ranged from 41,500 to 47,000 psi and 34,000 to 38,500 psi respectively. The best over-all stress-rupture strength at 1200° F was shown by the as-forged disc (1L). No improvement in strength was noted for the hot-cold worked disc (3L). The strengths of the heat-treated and aged discs, 2L and 2R, were similar.

At 1350° F the 100-hour rupture strengths of the as-forged disc (1L) and the quenched and aged discs (2L and 2R) were quite similar, but at 1000 hours the heat-treated discs showed a slight superiority over the as-forged disc. The same trend existed in tests at 1500° F. At 1350° F the 100-hour rupture strengths were all 28,000 psi and the 1000-hour rupture strengths ranged from 20,000 to 23,000 psi. At 1500° F the 100-hour rupture strengths were 16,500 to 18,500 psi and the 1000-hour rupture strengths ranged from 10,400 to 11,500 psi.

Inspection of the stress-rupture time curves shown in figure 6 indicates little change in slope with increased temperature of testing for discs 2L and 2R which were solution treated and aged. The as-forged disc (1L) showed a slightly greater change in slope between 1200° and 1350° F, and the considerably steeper slope for rupture in excess of 300 hours at 1500° F clearly indicates better properties are obtained at 1500° F by the use of heat treatment.

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Ductilities of the stress-rupture specimens measured after fracture were quite good. The elongation values of the as-forged disc (1L) were lower than for the heat-treated discs. Increased rupture time did not produce a significant change in ductility as is sometimes the case with other materials.

Time-Deformation Characteristics

A convenient method of describing the high-temperature strength of a material is by curves of stress against the time required for various total deformations. Data from both stress-rupture and creep tests are used to prepare such design curves. Such information along with the stress-rupture time curves gives design engineers a complete picture of the expected performance of an alloy under conditions of constant-tension stress. This information is incorporated in figures 8 to 16 for deformations of 0.1, 0.2, 0.5, and 1.0 percent at 1200°, 1350°, and 1500° F for time periods up to 3000 hours. Additional curves showing the time of transition from a minimum creep rate to the increasing rate of third-stage creep have been added so as to show when rapid elongation preceding failure starts.

The curves of stress time for total deformation were plotted from the data in tables V, VII, and IX. The data were taken from the time-deformation curves of the stress-rupture and creep tests. The time-deformation curves for the stress-rupture tests have not been included in this report but are on file at the National Advisory Committee for Aeronautics and in the Office of Naval Research, Navy Department, and may be obtained on loan for inspection if desired. The time-deformation curves for the creep tests are shown in figures 17 to 25.

Tables VI, VIII, and X show data scaled from the design curves in figures 8 to 16 and show the stresses to cause various total deformations from 0.1 to 5.0 percent in definite time periods of 1, 10, 100, 1000, and 2000 hours. For ease of comparison, similar data for the low-carbon N-155 alloy disc, NR66D, tested and reported previously in reference 2, have been included in tables VI, VIII, and X.

Creep Strengths

Many engineers are accustomed to base designs on creep rates, especially for long periods of service. For this reason, the creep-rate data have been collected from the time-deformation curves and are shown in table XI, and the logarithmic stress-creep rate curves for the tests at 1200°, 1350°, and 1500° F on the three discs 1L, 2L, and 2R are shown in figure 7. The creep rates used were either minimum rates or final rates from 1000-hour tests at 1200° F and 2000-hour tests at 1350° F and 1500° F. The creep strengths obtained from figure 7 were as follows:

Temperature			Stress for indicated creep rates (psi)						
(°F)	Disc	0.0001 percent/hr	0.00001 percent/hr						
1200	NR-66E-1L	23,500							
	NR-66E-2L	20,250							
	NR-66E-2R	23,200							
1350	NR-66E-1L	15,800	11,100						
	NR-66E-2L	14,500	12,000						
	NR-66E-2R	14,000	11,100						
1500	NR-66E-1L	7,600	a4,500						
	NR-66E-2L	9,500	8.000						
	NR-66E-2R	10,000	7,700						

aEstimated value.

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These creep strengths can be compared with the deformation strengths in tables VI, VIII, and X. The creep strengths for a rate of 0.0001 percent per hour at 1200° F are apparently safe for use for time periods up to 10,000 hours since extrapolation of the transition point curves (stage II to stage III creep rate) in figures 8 to 10 out to 10,000 hours indicates that at the stresses listed second-stage creep would still prevail.

In the tests at 1350° and 1500° F the situation is quite different. Extrapolation of the transition curves in figures 11 to 16 shows that in most cases increasing creep rates will occur between 1000 and 2000 hours at the stress for a creep rate of 0.0001 percent per hour, and with quite large total deformations ranging from 1.0 to 2.0 percent. In the tests at 1500° F on the heat-treated and aged discs (2L and 2R), transition to third-stage creep occurs, with a total deformation of less than 0.5 percent at 10,000 psi between 1000 and 2000 hours. At the lower stresses, which produced a creep rate of 0.00001 percent per hour, longer periods of service could be attained, but the slope of the stress-rupture time curves at higher stresses strongly suggests caution should be observed when extended service periods are contemplated.

Stability Characteristics

Some of the test specimens from each of the three discs were subjected to tensile, impact, and hardness tests at room temperature after creep testing at 1200°, 1350°, and 1500° F, with the results shown in table XII. The considerable decrease in impact strength and increase in hardness were the most significant changes observed. For all three discs the highest hardness was observed after testing at 1350° F, even though, in the case of disc 2L, the specimens were aged 24 hours at 1500° F prior to creep testing.

For the as-forged disc (1L), the yield strengths were slightly higher after creep testing at 1200° and 1350° F, with no significant change in tensile strength. After creep testing at 1500° F, the room-temperature tensile and yield strengths were slightly lower than for the disc in the as-forged condition.

For the heat-treated discs (2L and 2R), the room-temperature yield strengths were materially increased by creep testing at 1200° and 1350° F. For disc 2L tested at 1200° and 1350° F and disc 2R tested at 1350° F the ductilities were reduced to very low values. Testing at 1500° F reduced the tensile and yield strengths of disc 2L, but little change was noted in the strengths of disc 2R which was heat treated and aged at 1350° F prior to creep testing.

The microstructure was quite uniform from center to rim in each of the three discs and therefore only original microstructures at a center section are shown in figure 26 at magnifications of 100% and 1000%. The grain boundaries were not developed by the etching technique used on the as-forged disc (1L), but were clearly shown in the photomicrographs of the two heat-treated and aged discs (2L and 2R). The grain-size range was from about 1 to 4 A.S.T.M. grain size. Considerable precipitation within the grains was observed in the as-forged disc.

Disc 2R, which was water quenched from 2200° F and then aged 24 hours at 1350° F, showed less precipitation within the grains than the as-forged disc. Aging at 1500° F for 24 hours (disc 2L) considerably increased the amount of precipitated phase.

The photomicrographs of figures 27, 29, and 31 show the structures of the three discs 1L, 2L, and 2R after creep testing at 1200°, 1350°, and 1500° F. Little change in structure was observed as a result of 960 hours of testing at 1200° F, but about 2000 hours of testing at 1350° or 1500° F produced a heavy general precipitation and most heavy after testing at 1350° F. Table XII indicated this precipitation was accompanied by not very large changes in room-temperature strength, but a considerable decrease in ductility and impact resistance and by increased hardness. The photomicrographs suggest that testing at 1500° F may have produced some agglomeration of the precipitated phase, since for each of the discs the room-temperature strengths were also lower after testing at 1500° F than at 1350° F.

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Figures 28, 30, and 32 show the fractures and structures of specimens of the three discs after stress-rupture tests at 1200°, 1350°, and 1500° F. Fractures in the stress-rupture tests at 1200° F were largely transcrystalline, although as indicated in figure 30 there was some intergranular parting observed adjacent to the fracture in specimen 2K5. Fractures in specimens tested at 1350° F also appeared largely transcrystalline. Specimens tested in stress-rupture at 1500° F showed considerable intergranular cracking adjacent to the fracture.

DISCUSSION OF RESULTS

The tensile, rupture, and time-deformation data provide as nearly complete design information for these low-carbon N-155 discs as can be obtained in the laboratory from tests under constant-tensile stress.

The test data contained in this report apply only to the particular discs tested and fabricated and heat treated in the manner indicated. Considerable experience indicates that the properties depend on the particular manufacturing procedure used in the production of the discs. It should not be assumed that the properties herein reported apply to discs of a similar composition produced by another fabricator, or necessarily to similar discs produced by the same fabricator.

As an example of the variations that are encountered in data of the type presented, attention is called to tables VI, VIII, and X, which for purposes of comparison also include data on the as-forged disc of Low-Carbon N-155, NR-66D, (reference 2). When tested at 1200° F this previously tested as-forged disc was consistently superior to the three discs for which data are presented herein. This superiority of the as-forged NR-66D disc is maintained in tests at 1350° F except at low stresses producing creep rates of the order of 0.0000l percent per hour. In tests at 1500° F at lower stresses which produce lower rates of deformation and longer duration tests, the discs of heat-treated and aged Low-Carbon N-155 alloy are superior to the as-forged discs.

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November 18, 1946

REFERENCES

- Freeman, J. W., Reynolds, E. E., and White, A. E.: A Metallurgical Investigation of a Large Forged Disc of 19-9DL Alloy. NACA ACR No. 5Cl0, 1945.
- Freeman, J. W., Reynolds, E. E., and White, A. E.: A Metallurgical Investigation of a Large Forged Disc of CSA (234-A-5) Alloy. NACA ARR No. 5J16, 1945.
- Freeman, J. W., and Cross, Howard C.: A Metallurgical Investigation
 of a Large Forged Disc of Low-Carbon N-155 Alloy. NACA ARR
 No. 5K20, 1945. O.S.R.D. No. 6427, Serial No. M-617, August 4, 1945.

TABLE I.- SHORT-TIME HIGH-TEMPERATURE TENSILE PROPERTIES OF LOW-CARBON N-155 ALLOY DISCS, NR-66E.ª

(Pulled at 0.02 in. per min to yield strength, and 0.06 in. per min to rupture.)

		Specimen ^c location	Test temperature (°F)	Tensile strength (psi)	Propor- tional	Yield st	31)		Reduction
Discb	Specimen				limit (psi)	0.1 percent offset	0.2 percent offset	Elongation (percent)	of area (percent)
NR-66E-1L	1D1 1E1 1G2A 1G2B	Surface C Surface R Interior R Interior R	75 75 75 75	115,000 121,000 118,000 118,500	55,000	59,300 70,000 61,500 63,600	65,800 73,700 65,200 66,500	32 47 42 47	31.8 61.2 50.8 41.6
NR-66E-2L	2F8 2D8 2D3 2E3	Surface R Surface C Interior C Interior R	75 75 75 75	117,000 108,800 109,400 111,400	50,000	57,500 62,000 57,800 58,100	61,200 65,200 60,700 61,500	30 16 19 15	23.2 16.1 18.4 16.9
N R-66 E -2R	2K1 2L1 202A 2 M 3	Surface C Surface C Interior R Interior R	75 75 75 75 75	108,000 106,000 104,300 107,700	39,800	57,100 54,600 50,000 50,600	60,600 58,300 53,000 53,800	32 34 42 34	30.1 29.5 34.8 30.1
NR-66E-1L	1H1A 1B2	Surface R Interior R	1200 1200	d 75,625 79,650	36,100 34,750	48,000 40,500	50,000 42,500	22.3	25.0
NR-66E-2L	2HlA 2B2	Surface R Interior R	1200 1200		32,200 27,000	38,500 36,500	40,400 38,250	32.6	31.2
NR-66E-2R	2P1A 2J2	Surface R Interior R	1200 1200	d 52,500 64,700	25,200 21,000	31,600 27,650	33,100 29,100	26.0	28.8
NR-66E-1L	1B3 1H2A	Interior R Interior R	1350 1350		28,500 29,500	37,250 39,300	39,250 40,800	34.6 29.8	37.9 26.8
NR-66E-2L	2B3 2H2A	Interior R Interior R	1350 1350	60,700 59,300	37,500 26,000	42,500 35,300	44,000 37,300	32.0 31.7	31.8 32.1
NR-66E-2R	2J3 2P2A	Interior R Interior R	1350 1350	d 56,500 d 55,750	22,750 24,800	27,250 28,300	28,700 29,500	25.0	26.5
NR-66E-1L	1H1 1H3A	Surface R Interior R	1500 1500	45,100 43,700	20,350 29,400	28,350 34,300	35,900 35,300	33.0 30.8	40.1
NR-66E-2L	2Hl 2H4A	Surface R Surface R	1500 1500	42,000 42,500	21,500 23,500	32,000 32,400	33,500 34,200	33.0 33.5	33.1 29.8
NR-66E-2R	2P1 2P3A	Surface R Interior R	1500 1500	44,300 42,250	23,250 24,000	33,750 32,400	35,300 33,700	26.7 31.2	27.5 34.0

and Navy data.

All room-temperature tests were made on 1/4 inch-diameter specimens, gage length - 1 inch.

All high-temperature tests were made on 0.505-inch-ciameter specimens, gage length - 2 inches.

bHeat Treatments: NR-66E-1L As forged. NR-66E-2L 2200° F water quenched + 24 hours at 1500° F. NR-66E-2R 2200° F water quenched + 24 hours at 1350° F.

CSurface C = Surface specimen at center of disc.
Surface R = Surface specimen at rim of disc.
Interior C = Interior specimen at center of disc.
Interior R = Interior specimen at rim of disc.

dSpecimen broke in threads at stress shown.

TABLE II.- CHARPY NOTCHED-BAR IMPACT RESISTANCE AT ROOM TEMPERATURE, 1200°, 1350°, AND 1500° F FOR LOW-CARBON N-155 ALLOY DISCS, NR-66E.^a

Discb	Specimen	Location of test specimen in disc	Test temperature (°F)	Charpy impact strength (ft-lb)
NR-66E-1L	1C8 1D8	Surface C Surface R	Room	29 27
NR-66E-1L	R-66E-1L 1E6 Interior R 1C6 Interior C		Room	37 46 47
NR-66E-1L	1C2 1D2 1C3	Interior C Interior C Interior C	1200	58 43 64
NR-66E-1L	1E7 1F7 1C1	Interior R Interior R Surface C	1500	45 61 60
NR-66E-2L	2C1 2D1 2C8	Surface C Surface C Surface C	Room	5 4 5
NR-66E-2L	2F3 2C6 2D6	Interior R Interior C Interior C	Room	5 7 8
NR-66E-2L	2C2 2D2 2C7	Interior C 1200		21 21 28
NR-66E-2L	2D7 2E7 2F7	Interior C Interior R Interior R	1350	29 32 32
NR-66E-2L	2E6 2F6 2C3	Interior R Interior R Interior C	1500	31 33 38
NR-66E-2R	2L8 2M8 2N8	Surface C Surface R Surface R	Room	20 38 43
NR-66E-2R	2N3 2K6 2L6	Interior R Interior C Interior C	Room	17 28 29
NR-66E-2R	2L3 2L2 2K7	Interior C Interior C Interior C	1200	61 62 60
NR-66E-2R	2L7 2M7 2N7	Interior C Interior R Interior R	1350	57 57 65
NR-66E-2R	2M6 2N6 2K3	Interior R Interior R Interior C	1500	53 56 61

aNDRC and Navy data.

bHeat Treatments:
NR-66E-1L As forged.
NR-66E-2L 2200° F water quenched + 24 hours at 1500° F.
NR-66E-2R 2200° F water quenched + 24 hours at 1350° F.

CSurface C = Surface specimen at center of disc. Surface R = Surface specimen at rim of disc. InteriorC = Interior specimen at center of disc. InteriorR = Interior specimen at rim of disc.

TABLE III.- RUPTURE-TEST DATA FOR LOW-CARBON N-155 ALLOY DISCS, NR-66K, AT 1200°, 1350°, AND 1500° F.

Disca	Specimen	Specimen location	Test temperature (°F)	Stress (ps1)	Rupture time (hr)	Elongation (percent)	Reduction of area (percent)	Minimum creep rate (percent/hr)
d _{NR-66-1L}	1E5 1D5 1F5 1C5	CRR CRC CRR CRC	1200	55,000 47,500 45,000 40,000	10 40 178 613	7 10 8 15	12.1 17.8 18.9 17.8	.024
d _{NR-66E-1R}	1M5 1N5 1K5 1L5	CRR CRR CRC CRC	1200	50,000 45,000 40,000 37,500	51.5 143 237 504	35 36 31 19	43.7 41.8 24.5 21.7	
d _{NR-66E-2L}	2E5 2D5 2F5 2D4	CRR CRC CRR CRC	1200	50,000 45,000 40,000 35,000	26.5 80 205 1058	15 15 20 22	20.0 22.3 24.5 21.2	.039
d _{NR-66E-2R}	2M5 2L5 2K5	CRR CRC CRC	1200	50,000 40,000 35,000	8 188 1536	13 10 12	17.2 15.6 18.9	.0026
d _{NR-66E-3L}	3D5 3E5 3C5	CRC CRR CRC	1200	48,000 45,000 40,000	61 139 228	23 20 18	23.9 27.7 24.5	====
d _{NR-66E-1L}	1C4-1 1C4-2 1D4	CRC CRC CRC	1350	30,000 25,000 21,500	60 239 624	35 34 25	30.8 36.9 45.6	.055
dnr-66E-2L	f2C5 f2C4-1 f2C4-2	CRC CRC CRC	1350	30,000 25,000 21,500	52 258 729	26 36 35	35.0 39.8 39.8	.059
enr-66E-2L	2H3 2H2 2H4	CRR CRR CRR	1350	25,000 22,000 17,500	133 431 Disc def	52 46 continued aft	57.0 51.0 er 5 percent	.15 .037 .0014
d _{NR-66B-2R}	2P4 2K4-1 2L4-1 2P5 2K4-2 2L4-2	CRR CRC CRC CRR CRC	1350	32,500 30,000 27,500 27,500 25,000 23,000	46 96 60 276 392 1068	33 24 9 23 30 34	36.6 30.8 14.4 31.5 37.2 39.8	.029
♥NR-66E-1L	1D3 1H2 1E3 1E4 1F3 1F4	CRC CRR CRR CRR CRR CRR	1500	18,000 17,000 16,000 14,000 13,000 10,500	40.5 113.3 306.0 449.0 556.0 1084.0	39.0 15.1 12.0 7.0 12.0 4.0	36.6 30,8 16.0 12.5 11.6 8.8	.044 .012 .005 .004
enr-66E-2L	2E1 2E2 2F1 2G2	SRR CRR SRR CRR	1500	20,000 18,000 17,000 17,000	53 60 186 Disc	41 61 46 continued aft	43.0 52.1 64.5 er 2 percent	.044
	2F2 2E4 2F4	CRR CRR CRR		15,000 13,000 11,000	323 579 1885	41 44 37	58.1 54.8 43.4	.024 .01 .0013
•NR-66E-2R	2M1 2M2 2N1 2N2 2P3	SRR CRR SRR CRR CRR	1500	22,500 20,000 17,000 15,000 15,000	def	42 34 40 42 continued aft		
	2P4 2N4 2J1	SRR CRR SRR		13,500 13,500 10,000	Disc	continued aft ormation 37 21	er 1 percent 53.3 33.0	.0034 .004 .0001

**RR-66B-1L: As forged.

NR-66B-1R: As forged + 24 hours at 1500° F.

NR-66B-2L: 2200° F water quenched + 24 hours at 1500° F.

NR-66B-2L: 2200° F water quenched + 24 hours at 1500° F.

NR-66B-3L: 2250° F water quenched + 3 percent hot-cold work at 1500° to 1200° F + 24 hours at 1500° F.

cpercent in 1 inch.

 ${\rm ^{d}NACA}$ data (specimens were 0.160 in. in diameter with a gage length of 1 in.)

 $^{\mathbf{e}}$ NDRC and Navy data (specimens were 0.250 in. in diameter with a gage length of 1.3 in.).

f Data from this test not used in design curves.

TABLE IV.- RUPTURE STRENGTHS OF LOW-CARBON N-155 ALLOY DISCS, NR-66E, AT 1200°, 1350°, AND 1500° F.

	Test temperature		produce rupture (psi		time periods	
Disca	(°F)	10 hr	100 hr	1000 hr	2000 hr	
bnr-66E-1L	1200	55,000	46,000	38,500	d ₃₆ ,500	
b _{NR-66E-1R}	1200		47,000	33,500	d ₃₀ ,000	
bnR-66E-2L	1200	d55,000	44,000	35,000	d ₃₃ ,000	
bnr-66E-2R	1200	48,000	41,500	36,000	34,500	
bnr-66E-3L	1200		46,000	d34,000		
bnr-66E-1L	1350	d39,000	28,000	20,000	d _{18,000}	
bnr-66E-2L	1350	d 38,000	28,000	21,000	d19,000	
b _{NR-66E-2R}	1350	d ₃₄ ,500	28,000	23,000	22,000	
c _{NR-66E-1L}	1500		16,500	11,800	10,400	
c _{NR-66E-2L}	1500		18,000	12,200	10,700	
c _{NR-66E-2R}	1500	23,700	18,500	13,000	11,500	

^aHeat Treatments:

Treatments:
NR-66E-1L As forged.
NR-66E-1R As forged + 24 hours at 1500° F.
NR-66E-2L 2200° F water quenched + 24 hours at 1500° F.
NR-66E-2R 2200° F water quenched + 24 hours at 1350° F.
NR-66E-3L 2250° F water quenched + 3 percent hot-cold work at 1500° to 1200° F + 24 hours at 1500° F.

bNACA data.

CNDRC and Navy data.

dEstimated.

TABLE V	STRESS-TIME FOR TOTAL-DEFORMATION DATA AT 1200°	F
	FOR LOW-CARBON N-155 ALLOY DISCS, NR-66E.a	

			Initial	Time f	or ind	icated	total	defor	mation		nsition to -stage creep
Discb	Specimen	Stress (psi)	deformation (percent)	0.1%	0.2%	(h:	r)	2.0%	5.0%	Time (hr)	Deformation (percent)
NR-66 E-1L	1A2 1A3 1C5 1F5	25,000 30,000 40,000 45,000	0.114 .131 .22 .55	=======================================	87 21 	1150 145 2	617 11 5	46 30	325 150	335 150	5.3 5.0
NR-66E-2L	2A3 2A2 2D4 2F5	20,000 25,000 35,000 40,000	.080 .111 .18 .40	60	1290 85 	625 22	 57 6	165 24	 515 96	 475 90	 4.5 4.7
NR-66E-2R	212 213 2K5	25,000 30,000 35,000	.139 .61 c1.00	==	245	==	335	 47	885	975	5.2

aNACA data.

bHeat Treatments:

NR-66E-1L As forged.

NR-66E-2L 2200° F water quenched + 24 hours at 1500° F.

NR-66E-2R 2200° F water quenched + 24 hours at 1350° F.

cApproximate.

TABLE VI.- STRESS-TIME FOR TOTAL-DEFORMATION CHARACTERISTICS AND CREEP STRENGTHS AT 1200° F FOR LOW-CARBON N-155 ALLOY DISCS, NR-66E^a.

	Total deformation	Stre			deformat e periods		Creep strength (Based on creep rates at 1000 hr) (psi)		
Discb	(percent)	1 hr	10 hr	100 hr	1000 hr	2000 hr	0.00010% per hr	0.00001% per hr	
NR-66D NR-66E-1L NR-66E-2L NR-66E-2R	0.1 .1 .1	21,500	20,000	17,500	14,500	13,500	28,000 23,500 20,250 23,200	15,000 	
NR-66D NR-66E-1L NR-66E-2L NR-66E-2R	.2 .2 .2 .2	34,000	31,500	28,000 25,000 24,500 26,000	24,000 20,500 c _{23,000}	23,000			
NR-66D NR-66E-1L NR-66E-2L NR-66E-2R	.5 .5 .5	44,500 41,500	39,500 36,000	35,000 30,500 30,000	30,000 25,500 23,500	28,500 23,500 			
NR-66D NR-66E-1L NR-66E-2L NR-66E-2R	1.0 1.0 1.0 1.0	51,000	45,500 40,500 40,000	40,000 34,500 33,000 c _{31,000}	35,000 28,500 29,000	33,500			
NR-66D NR-66E-1L NR-66E-2L NR-66E-2R	Transition Transition Transition Transition			51,500 44,500 40,500	39,500 37,000 32,000 35,000	36,000			

aNACA data.

bHeat Treatments:

NR-66D: As forged + 2 hours at 1200° F.

NR-66E-1L: As forged.

NR-66E-2L: 2200° F water quenched + 24 hours at 1500° F. NR-66E-2R: 2200° F water quenched + 24 hours at 1350° F.

CEstimated values.

TABLE VII.- STRESS-TIME FOR TOTAL DEFORMATION DATA AT 1350° F FOR LOW-CARBON N-155 ALLOY DISCS, NR-66E.

		Stress	Initial deformation	Time	for ind	icated (hr)	Transition to third- stage creep Time Deformation				
Disca	Specimen	(psi)	(percent)	0.1%	0.2%	0.5%	1%	2%	5%	(hr)	(percent)
NR-66E-1L	(b) {1G4 1B4 1A4 1G1 (c) {1D4 1C4-2	10,000 12,000 15,000 20,000 21,500 25,000	0.053 .062 .072 .15 .10	65 37 14 	360 160 85 2 	g ₄ 900 447 32 6 1	120 22 5	 60 20	 200 75	 310 130	 6.4 8.0
NR-66E-2L	(2G3 2B4 2A4 2H4 2H4 2G4 2H2 2H2 (d2H3 (c)H2C4-1	10,000 12,000 15,000 17,500 20,000 22,000 25,000 21,500 25,000	.045 .052 .083 .115 .175 .122 .153 .105	127 58 20 	450 200 125 5 1 	625 36 11 4 1 15 3	114 36.5 16 4 36 9	622 119 37 11 70 26	 112 60 235 68	715 150 45 290 120	2.15 6.5 3.6 5.6 8.2
N R-66E-2R	(b) 203 2J4 214 204 2L4-2 2K4-2 2P5 2K4-1 2P4	10,000 12,000 15,000 20,000 23,000 25,000 27,500 30,000 32,500	e.04 e.072 e.085 f.10 .13 .14 .18 .19 .21	230 40 10 	540 175 90 13 	480 90 12 4 3	 g220 48 14 8	112 44 28 10 5	 600 112 79 28 16	 550 250 160	4.5 9.0 8.8

aHeat Treatments:

NR-66E-1L: As forged.

NR-66E-2L: 2200° F water quenched + 24 hours at 1500° F. NR-66E-2R: 2200° F water quenched + 24 hours at 1350° F.

bNDRC and Navy data.

CNACA data.

dData from this test not used in design curves.

eInitial deformation obtained from load-off reading.

f Initial deformation calculated from modulus of elasticity.

g Estimated.

TABLE VIII.- STRESS-TIME FOR TOTAL DEFORMATION CHARACTERISTICS AND CREEP STRENGTHS AT 1350° F FOR LOW-CARBON N-155 ALLOY DISCS, NR-66E^a.

	Total deformation	Stre		cated ti	l deforma me period		Creep strength (Based on creep rates at 1000 hr) (psi)		
Discb	(percent)	1 hr	10 hr	100 hr	1000 hr	2000 hr	0.0001% per hr	0.00001% per hr	
NR-66D NR-66E-1L NR-66E-2L NR-66E-2R	0.1 .1 .1	17,000 c18,600 c18,300	13,800 15,500 15,700 15,000	11,000 10,600 10,900	8,000		16,000 15,800 14,500 14,000	7,900 11,100 12,000 11,100	
NR-66D NR-66E-1L NR-66E-2L NR-66E-2R	.2 .2 .2 .2	26,000 20,800 20,000	21,400 17,800 17,200 20,400	16,700 14,200 13,700 14,400	12,000	c10,700			
NR-66D NR-66E-1L NR-66E-2L NR-66E-2R	•5 •5 •5 •5	24,500 25,000	26,500 21,400 20,200 24,000		17,200 c13,900 c14,000 c14,100	c _{15,900} c _{13,200}			
NR-66D NR-66E-1L NR-66E-2L NR-66E-2R	1.0 1.0 1.0 1.0		23,200 22,900 26,900	25,000 20,200 17,800 21,600	19,500	=====			
NR-66D NR-66E-1L NR-66E-2L NR-66E-2R	Transition Transition Transition Transition			24,000 26,000 23,000 27,800	18,000 17,000				

aNACA, NDRC and Navy data.

bHeat Treatments:

NR-66D: As forged + 2 hours at 1200° F.

NR-66E-1L: As forged.
NR-66E-2L: 2200° F water quenched + 24 hours at 1500° F.
NR-66E-2R: 2200° F water quenched + 24 hours at 1350° F.

CEstimated values.

TABLE IX.- STRESS-TIME FOR TOTAL DEFORMATION DATA AT 1500° F FOR LOW-CARBON N-155 ALLOY DISCS, NR-66Ea.

		Stress	Initial deformation	Tin	ne for indi		tion to third- age creep Deformation				
Discb	Specimen	(psi)	(percent)	0.1%	0.2%	(hr)	1%	2%	5%	(hr)	(percent)
NR-66E-1L	1G3 1A1 1B1 1F4 1F3 1E4 1E3 1H2	5,000 7,000 10,000 10,500 13,000 14,000 16,000 17,000	0.031 .042 .065 	65 37 9 8 4 	d4800 400 47 26 8	d9000 615 108 40 38 20	1963 360 97 96 64 16	740 320 290 138 37	536 430 290	1400 550 360 250 160 25	0.8 1.40 2.15 1.72 2.30 1.30
NR-66E-2L	2H2 2A1 2B1 2F4 2E4 2F2 C2F1 2G2	5,000 7,000 10,000 11,000 13,000 15,000 17,000	.038 .037 .059 .115	750 210 9 	d8700 52 25	1620 125 48 5 11 3.1	2035 475 88 16 23 8.7	785 186 65 45 17	1135 315 160 90	1200 600 145 50 28 10	0.375 1.40 1.50 1.70 1.20
NR-66E-2R	2P2 2I1 2J1 2P4 2N2 2P3	5,000 7,000 10,000 13,500 13,500 15,000	.025 .046 .066 .078 	425 10 0.2	d18,000 45 7 2.7	1240 55 15.4	1615 174 37.5	1775 190 74	2255	800 120 50	0.38 0.75

aNDRC and Navy data.

bHeat Treatments:

NR-66E-1L: As forged. NR-66E-2L: 2200° F water quenched + 24 hours at 1500° F. NR-66E-2R: 2200° F water quenched + 24 hours at 1350° F.

^cData from this test not used in design curves.

dEstimated.

TABLE X.- STRESS-TIME FOR TOTAL DEFORMATION CHARACTERISTICS AND CREEP STRENGTHS AT 1500° F FOR LOW-CARBON N-155 ALLOY DISCS, NR-66E^a.

	Total deformation	Stre	s to cau indic	se total ated tim (psi)	Creep strength (Based on minimum creep rates) (psi)			
Discb	(percent)	1 hr	10 hr	100 hr	1000 hr	2000 hr	0.00010% per hr	0.00001% per hr
NR-66D NR-66E-1L NR-66E-2L NR-66E-2R	0.1 .1 .1	16,000 cl3,500 11,800	11,500 9,800 10,500 10,000	7,700 4,800 7,500 8,200	6,800 6,800	 c6,600	8,700 7,600 9,500 10,000	c5,000 c4,500 8,000 7,700
NR-66D NR-66E-1L NR-66E-2L NR-66E-2R	.2 .2 .2 .2	16,000 15,200	16,800 12,500 12,200 12,700	11,000 8,800 9,600 9,600	6,800 c6,200 c8,300 8,400	c5,700 c7,800 c8,000		
NR-66D NR-66E-1L NR-66E-2L NR-66E-2R	.5 .5 .5		16,500 14,600 15,400	15,500 11,000 11,300 12,800	10,500 9,200 10,200 10,200	c9,300 c8,600 		
NR-66D NR-66E-1L NR-66E-2L NR-66E-2R	1.0 1.0 1.0		16,200 c16,300	17,400 13,400 12,800 14,000	12,000 10,200 10,500 10,800	10,000 10,000 9,700		
NR-66D NR-66E-1L NR-66E-2L NR-66E-2R	Transition Transition Transition Transition		17,000 c17,800	16,400 16,300 13,700 13,800	11,200 10,200 10,300 9,600	9,700 c9,800 		

and Navy data.

bHeat Treatments:

NR-66D: As forged + 2 hours at 1200° F.

NR-66E-1L: As forged. NR-66E-2L: 2200° F water quenched + 24 hours at 1500° F. NR-66D-2R: 2200° F water quenched + 24 hours at 1350° F.

CEstimated values.

		t'	Te t'em atu		Stress	Duration	Deformation upon application of load	Creep	rate, per	cent per	hour at	Total d	eformat	ion, per	cent at
Disca	Spec	imen	(°F)	(ps1)	(hr)	(percent)	500 hr	100 hr	1500 hr	2000 hr	500 hr	1000 hr	1500 hr	2000 hr	
NR-66E-1L	(b)	1A3 1A2	1200	30,000 25,000	960 1078	0.131	0.00078	0.00051			0.915	1.210			
NR-66E-2L	(b)	2A2 2A3	1200 1200	25,000	1078 1292	.111	.00049				.438	.684		====	
NR-66E-2R	(b)	2I3 212	1200 1200	30,000 25,000	960 1077	.61 .139	.00090	.00078			1.16	1.56			
N R-66E-1L	(c)	1G1 1A4 1B4 1G4	1350 1350 1350 1350	20,000 15,000 12,000 10,000	267 2016 2015 2086	.15 .073 .062 e.053	d.0033 .000352 .000180 .000175	.000156		0.000054 .000020 N11	d1.35 .521 .384 .226	.614 .416 .304	0.666 .432 .334	0.700 .442 .340	
NR-66E-2L	(c)	2G4 2A4 2B4 2G3	1350 1350 1350 1350	20,000 15,000 12,000 10,000	260 2012 2016 2012	.175 e.083 .052 .045	f.004 .000336 .000166 .00012		.000023	.000023 .000019 .000018	f _{2.99} .469 .323 .222	.531 .362 .243	.566 .378 .257	.583 .390 .268	
N R-66 E -2R	(c)	204 214 2J4 203	1350 1350 1350 1350	20,000 15,000 12,000 10,000	214 1990 2015 2008	g.10 e.085 e.072 g.040	h.0038 .000302 .000188 .000124	.000057	.000032	.000033 .000023 .000014	h.976 .513 .332 .196	.556 .390 .234	.583 .412 .246	.603 .426 .259	
NR-66E-1L	(c)	1B1 1A1 1G3	1500 1500 1500	10,000 7,000 5,000	2033 2037 2010	.065 .042 .031	.00033 .000085 .000030	.00033 .000055 .000036		.00053 .000040 .000013	.457 .212 .150	.627 .240 .161	.812 .262 .170	1.05 .290 .172	
NR-66E-2L		2B1 2A1 2H2	1500 1500 1500	10,000 7,000 5,000	2611 2775 2252	e.059 e.037 .038	.00011 .000036 .000020	.00013 .000022 .000010		.00198 .000010 N11	.307 .119 .096	.357 .135 .104	.466 .143 .110	.940 .147 .110	
NR-66E-2R	(c)	2J1 2I1 2P2	1500 1500 1500	10,000 7,000 5,000	1 ₃₀₆₇ 2204 1485	.066 .046 .025	.00010 .000080 .000020	.00024 .000010 N11	.00150 .000005 N11	.00475	.350 .106 .065	.425 .130 .070	.760 .132 .070	2.74	

TABLE XI.- CREEP TEST DATA AT 1200°, 1350°, AND 1500° F FOR LOW-CARBON N-155 ALLOY DISCS, NR-66E

aHeat Treatments:

NR-66E-1L: As forged.

NR-66E-2L: 2200° F water quenched + 24 hours at 1500° F.

NR-66E-2R: 2200° F water quenched + 24 hours at 1350° F.

bNACA data.

CNDRC and Navy data.

dwhen discontinued at 267 hours.

evalue obtained from contraction when load was removed.

fwhen discontinued at 260 hours.

gValue obtained using the Modulus of Elasticity.

hwhen discontinued at 214 hours.

¹Broke, 21.4% elongation, 33.0% reduction of area.

TABLE XII.- EFFECT OF CREEP TESTING ON THE ROOM-TEMPERATURE PHYSICAL PROPERTIES OF LOW-CARBON N-155 ALLOY DISCS, NR-66E.

			Residual room-temperature properties								
Disca	Specimen	Prior testing conditions Temp. Stress Time (°F) (psi) (hr)	Tensile strength (psi)		yield s (psi) 0.1%	o.2%	Proportional limit (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)	Izod impact strength (ft-lb)	Vickers hardnes
NR-66E-1L	(b) \\ \begin{cases} \text{62A} \\ \text{62B} \\ \text{CB} \\ \text{1H4-A} \\ \text{(b)} \end{cases} \text{1A4-B} \\ \text{1A3} \\ \text{(c)} \end{cases} \text{1A2} \\ \text{1B4} \\ \text{1B4} \\ \text{1B4} \\ \text{1B3} \\ \text{1A1} \end{cases} \text{1A3} \\ \text{1B4} \\ 1	Original condition		62,500	61,500 63,600 69,400 67,000 57,500	71,500 71,800	47,700 44,800 50,000 44,400 	42 47 22 f7.5	50.8 41.6	d ₆₀ , 60 e ₇₁ , 41 e ₆₃ , 53 d ₁₁ , 12 e _{2.5} , 2 e ₁₀ , 5.5	215 215 249 293 233
NR-66E-2L	(b) {2D3 2E3 2H4 (b) {2H3 2G1 (c) {2A3 {2A2 (2A3 (b) {2B4 2H2 2A1	Original condition		60,000	58,100 65,500 65,400	60,700 61,500 68,500 54,500	48,100 48,900 37,500 44,700 	19 15 85 3.5	18.4 16.9 5.4 3.1 	d6, 6 e10, 6 e7, 7 d2, 3 e1.5, 1.5 e2.5, 2	240 247 280 237
N R-66 E -2R	(b) \$202-A 12M3 2201 (b) \$202-B 22P4 (c) \$212 213 \$203 (b) \$2J4 2P2 211	Original conditiondodo 1200 25,000 1070 1200 30,000 960 1350 10,000 2018 1350 12,000 2015 1500 5,000 1485 1500 7,000 2204	107,700	51,500	57,000	53,000 53,800 60,000 -73,800 -54,100	39,300 38,800 37,500 -44,900 27,000	42 34 24 3.0 -4.0	34.8 30.1 19.2 4.3 	d22, 26 e30, 40 e26, 31 d4, 10 e5, 3.5 e3, 3.5	205 224 276 238

a Heat Treatments:
 NR-66E-1L: As forged.
 NR-66E-2L: 2200° F water quenched + 24 hours at 1500° F.
 NR-66E-2R: 2200° F water quenched + 24 hours at 1350° F.

bNDRC and Navy data.

CNACA data.

dSpecimens were 0.365-inch square with a 0.050-inch V-notch.

eSpecimens were 0.450-inch diameter, V-notch.

fBroke in fillet.

Especimen fractured in gage mark.

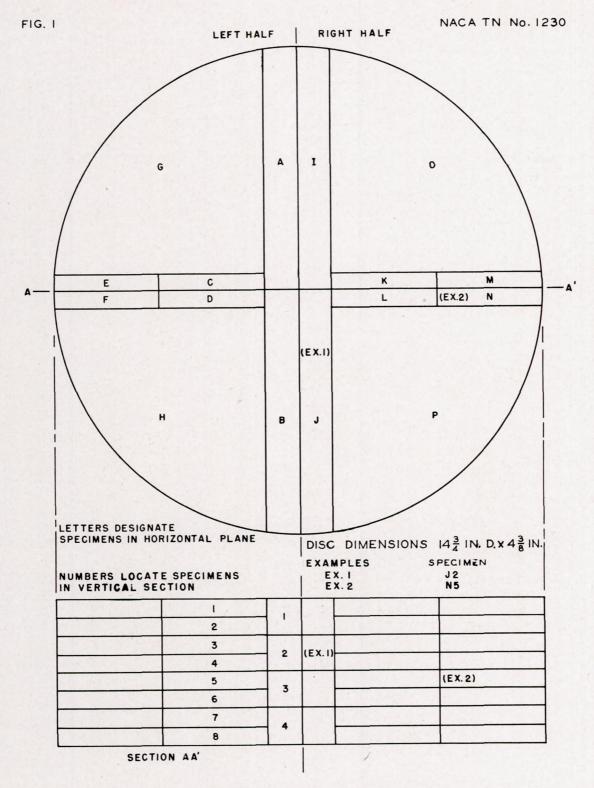


FIGURE I.—LOCATION OF TEST COUPONS IN LOW-CARBON N-155 ALLOY DISCS, NR-66E.

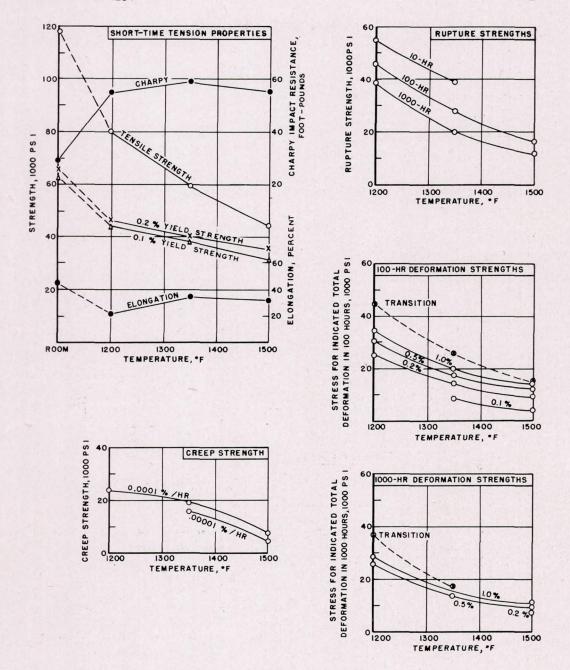


FIGURE 2, SUMMARY OF THE PROPERTIES OF THE LOW-CARBON N-155 ALLOY DISC, NR-66E-IL. (TESTED AS FORGED.)

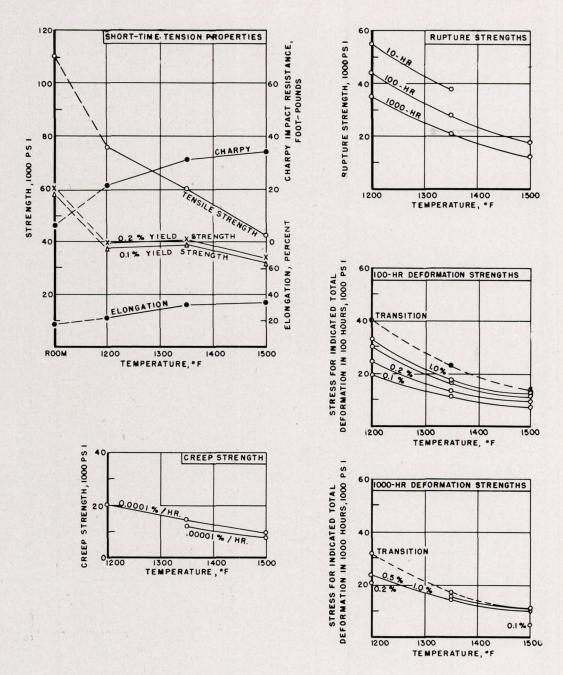


FIGURE 3.—SUMMARY OF THE PROPERTIES OF THE LOW-CARBON N-155 ALLOY DISC,NR-66E-2L.

(TESTED AS WATER-QUENCHED FROM 2200 °F AND AGED 24 HOURS AT 1500 °F)

FIG. 4

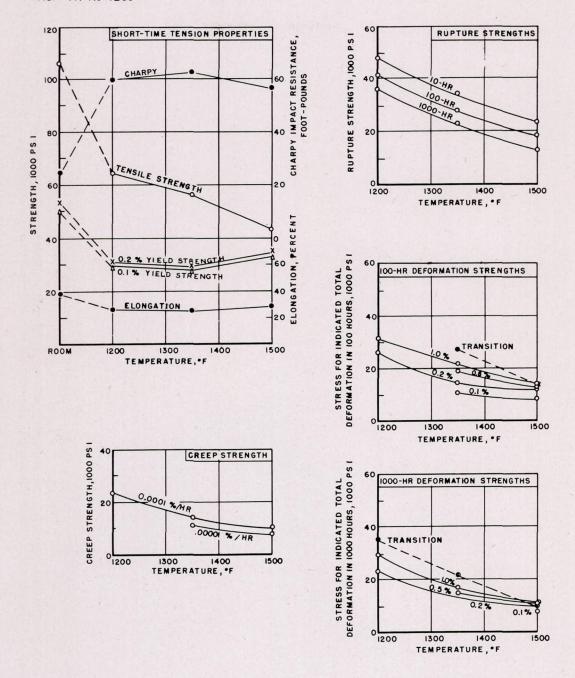


FIGURE 4.- SUMMARY OF THE PROPERTIES OF THE LOW-CARBON N-155 ALLOY DISC, NR-66E-2R. (TESTED AS WATER-QUENCHED FROM 2200°F AND AGED 24 HOURS AT 1350°F.)

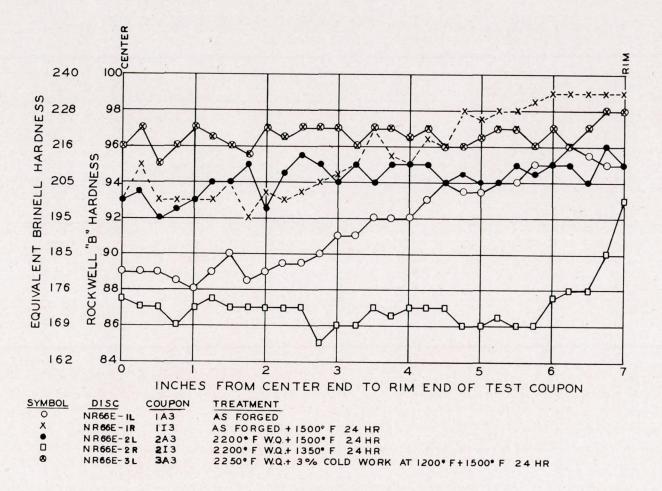
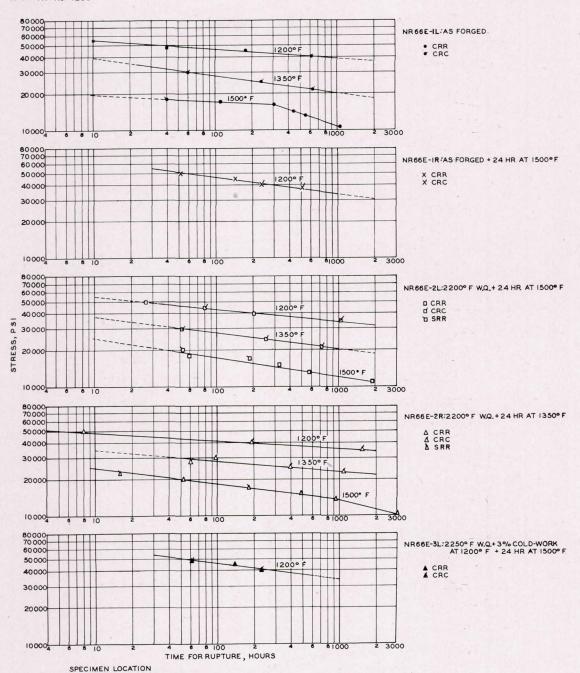


FIGURE 5.- VARIATION IN HARDNESS FROM CENTER TO RIM OF CENTER PLANE; COUPONS OF LOW-CARBON NH55 ALLOY DISCS, NR66E.



CRR CENTER PLANE RADIAL SPECIMEN NEAR RIM
CRC CENTER PLANE RADIAL SPECIMEN NEAR CENTER
SRR SURFACE PLANE RADIAL SPECIMEN NEAR CENTER
SRR SURFACE PLANE RADIAL SPECIMEN NEAR RIM
FIGURE 6.—STRESS—RUPTURE—TIME CURVES AT 1200°, 1350°, AND 1500° F FOR LOW-CARBON
N-155 ALLOY DISCS, NR66E.

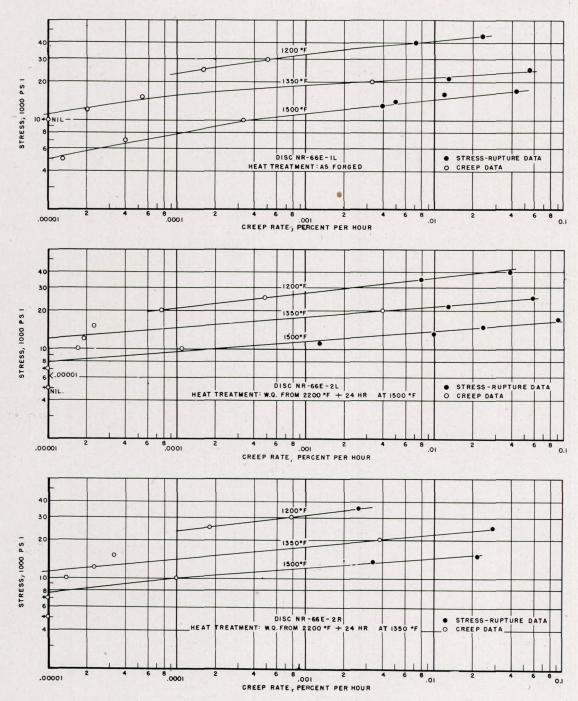
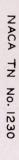
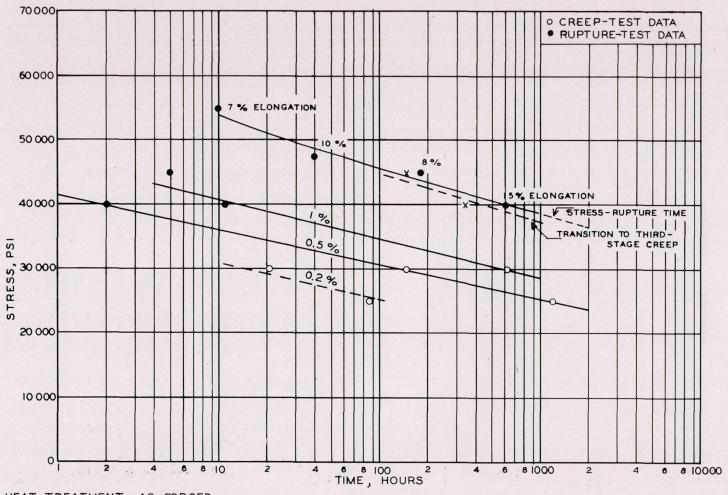


FIGURE 7.- STRESS-CREEP-RATE CURVES FOR LOW-CARBON N-155 ALLOY DISCS, NR-66E.



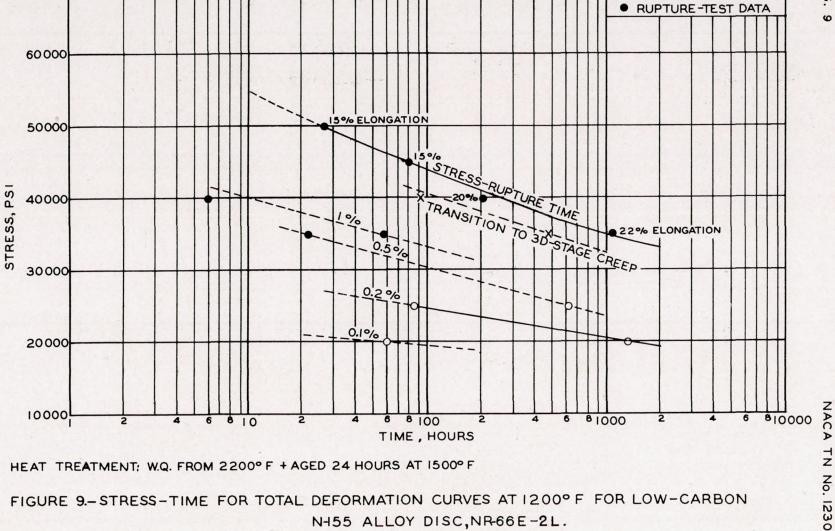


HEAT TREATMENT: AS FORGED

FIGURE 8.-STRESS-TIME FOR TOTAL DEFORMATION CURVES AT 1200° F FOR LOW-CARBON N.55 ALLOY DISC, NR66E-IL.

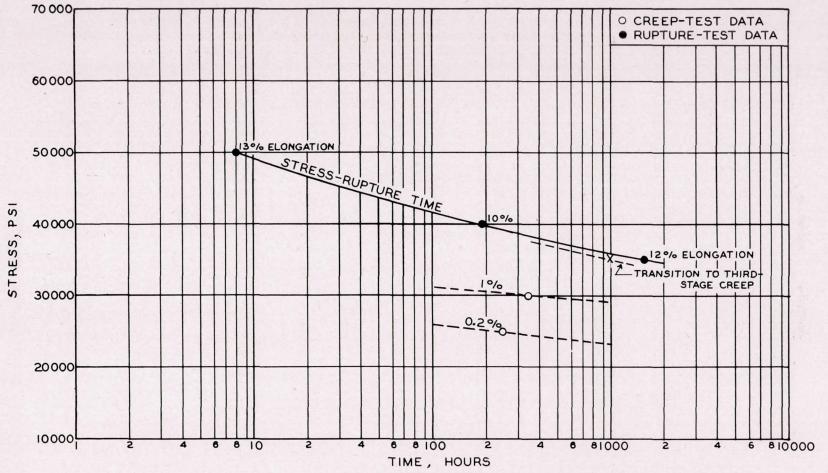


O CREEP-TEST DATA



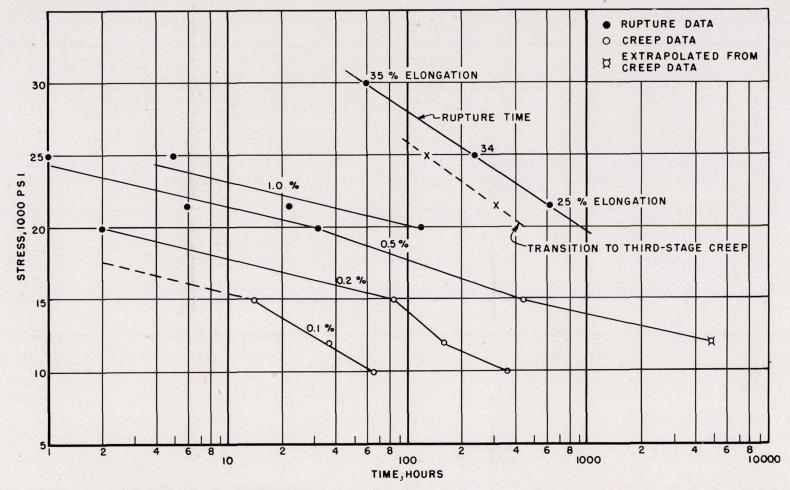
70000

FIGURE 9.- STRESS-TIME FOR TOTAL DEFORMATION CURVES AT 1200° F FOR LOW-CARBON N+55 ALLOY DISC, NR-66E-2L.



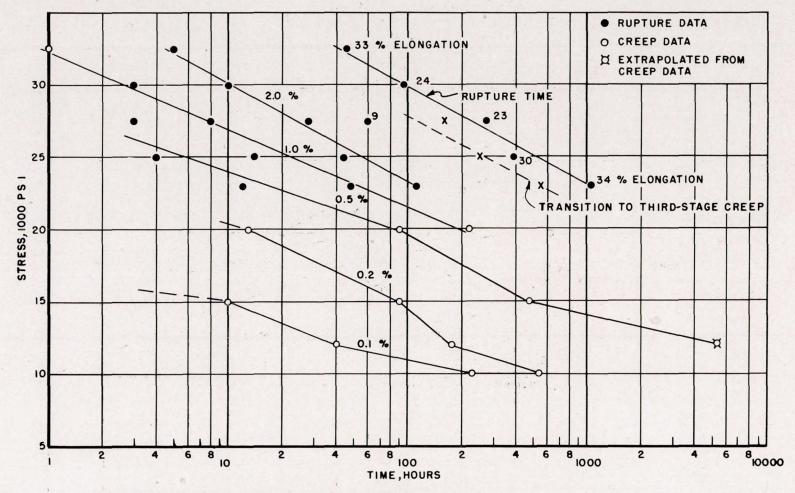
HEAT TREATMENT: W.Q. FROM 2200° F + AGED 24 HOURS AT 1350° F

FIGURE 10.-STRESS-TIME FOR TOTAL DEFORMATION CURVES AT 1200° F FOR LOW-CARBON N-155 ALLOY DISC, NR-66E-2R.



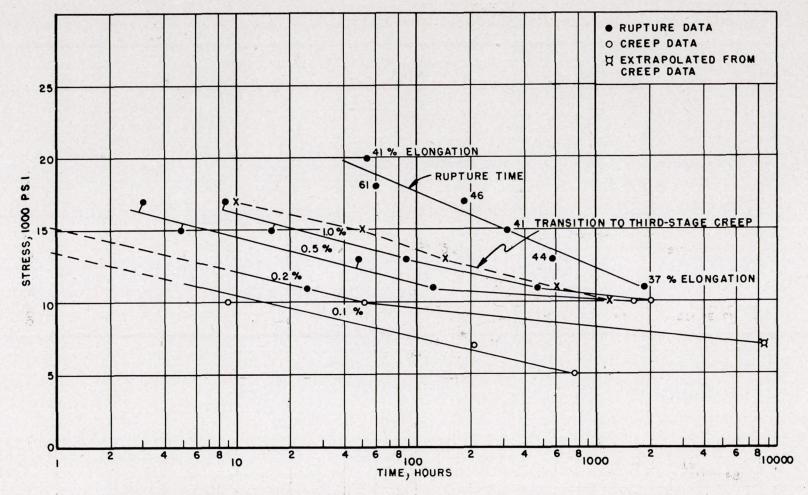
HEAT TREATMENT: AS FORGED
FIGURE II.—STRESS VS. TIME FOR TOTAL DEFORMATION CURVES AT 1350 °F FOR LOW-CARBON
N-155 ALLOY DISC, NR-66E-IL.

HEAT TREATMENT: W.Q. FROM 2200 °F + 24 HOURS AT 1500 °F
FIGURE 12,— STRESS VS. TIME FOR TOTAL DEFORMATION CURVES AT 1350 °F FOR LOW-CARBON
N-155 ALLOY DISC, NR-66E-2L.

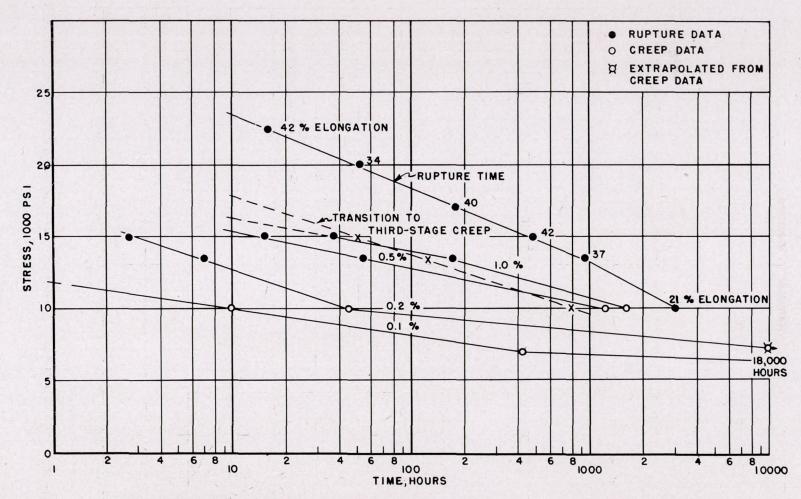


HEAT TREATMENT: W.Q. FROM 2200° F + 24 HOURS AT 1350° F
FIGURE 13:-STRESS VS. TIME FOR TOTAL DEFORMATION CURVES AT 1350° F FOR LOW-CARBON
N-155 ALLOY DISC, NR - 66E-2R.

HEAT TREATMENT: AS FORGED
FIGURE 14. STRESS VS. TIME FOR TOTAL DEFORMATION CURVES AT 1500 °F FOR LOW-CARBON N-155 ALLOY DISC, NR-66E-IL.



HEAT TREATMENT: W.Q. FROM 2200 °F + 24 HOURS AT 1500 °F
FIGURE 15.-STRESS VS. TIME FOR TOTAL DEFORMATION CURVES AT 1500 °F FOR LOW-CARBON
N-155 ALLOY DISC,NR-66E-2L.



HEAT TREATMENT: W.Q. FROM 2200 °F + 24 HOURS AT 1350 °F
FIGURE 16.-STRESS VS. TIME FOR TOTAL DEFORMATION CURVES AT 1500 °F FOR LOW-CARBON
N-155 ALLOY DISC, NR-66E-2R.

FIG. 17 NACA TN No. 1230

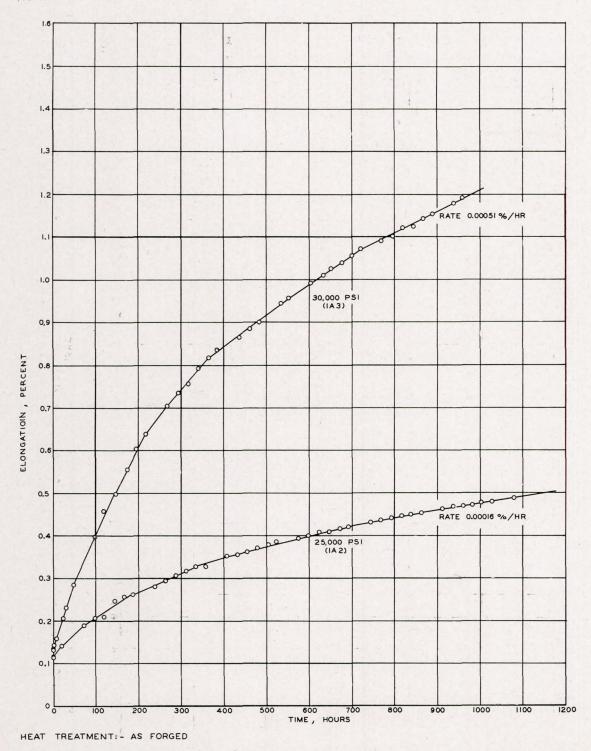
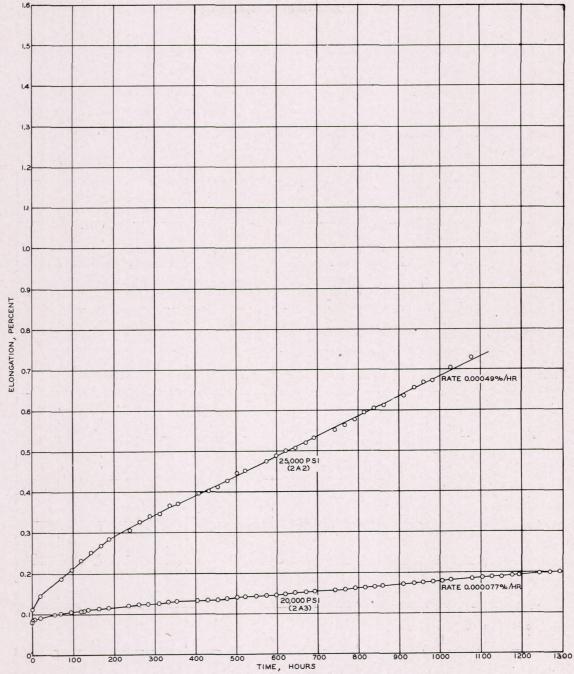


FIGURE 17. - TIME-ELONGATION CURVES AT 1200° F FOR LOW-CARBON NI55 DISC, NR66E-IL.

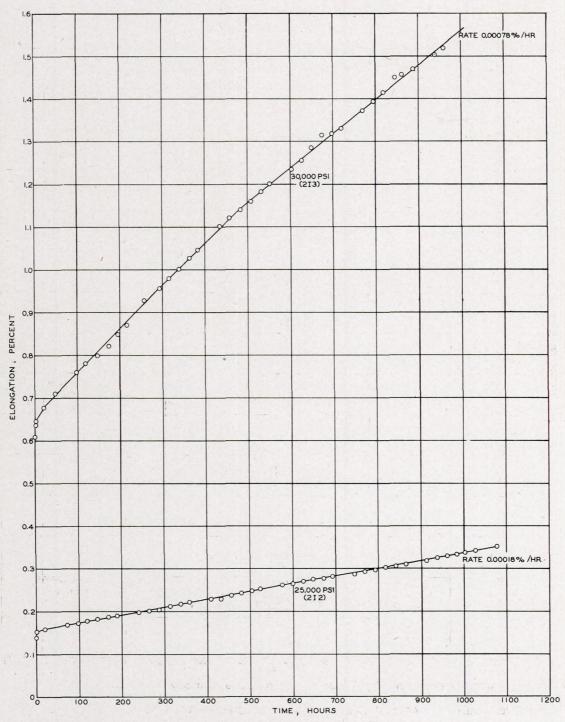
NACA TN No. 1230



HEAT TREATMENT:- WATER QUENCHED FROM 2200° F +AGED FOR 24 HOURS AT 1500° F

FIGURE 18.-TIME-ELONGATION CURVES AT 1200° F FOR LOW-CARBON N-155 DISC,NR-66E-2L.

FIG. 19 NACA TN No. 1230



HEAT TREATMENT-WATER QUENCHED FROM 2200° F + AGED FOR 24 HOURS AT 1350° F.

FIGURE 19.-TIME-ELONGATION CURVES AT 1200° F FOR LOW-CARBON N+55 DISC, NR66E-2R.

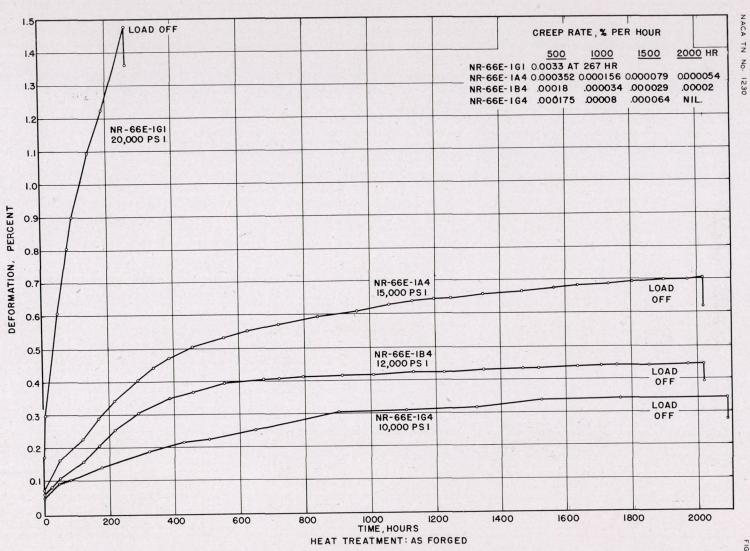


FIGURE 20.-TIME-DEFORMATION CURVES AT 1350°F FOR LOW-CARBON N-155 ALLOY DISC, NR-66E-1L.



FIG. 21



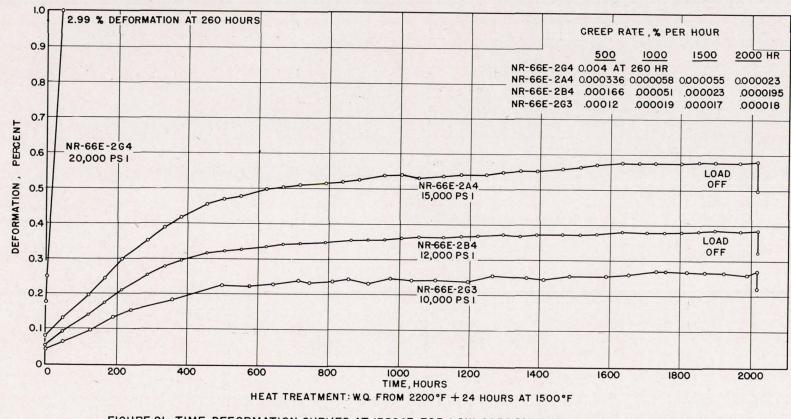


FIGURE 21-TIME-DEFORMATION CURVES AT 1350°F FOR LOW-CARBON N-155 ALLOY DISC, NR-66E-2L.

FIGURE 22- TIME-DEFORMATION CURVES AT 1350°F FOR LOW-CARBON N-155 ALLOY DISC, NR-66E-2R.

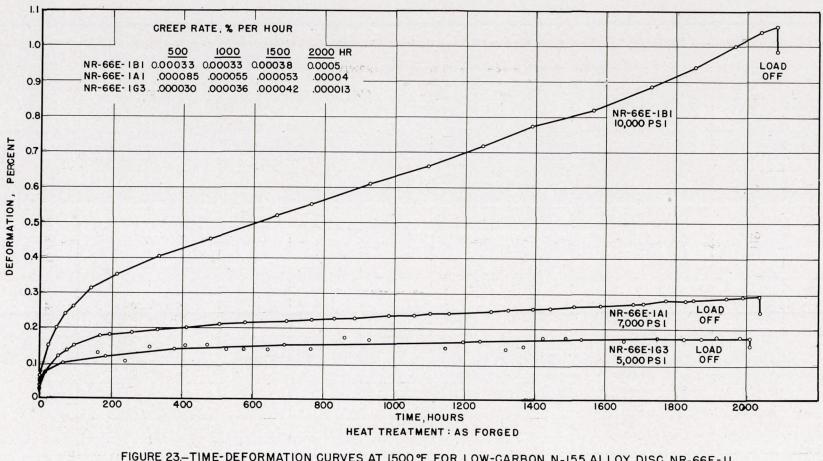


FIG.

23

FIGURE 23.-TIME-DEFORMATION CURVES AT 1500 °F FOR LOW-CARBON N-155 ALLOY DISC, NR-66E-IL.

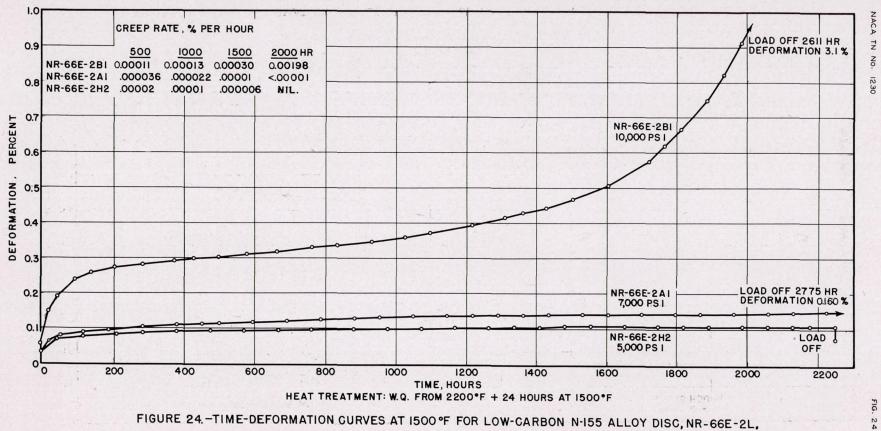


FIGURE 24 -TIME-DEFORMATION GURVES AT 1500 °F FOR LOW-CARBON N-155 ALLOY DISC, NR-66E-2L.



T Z

FIG.

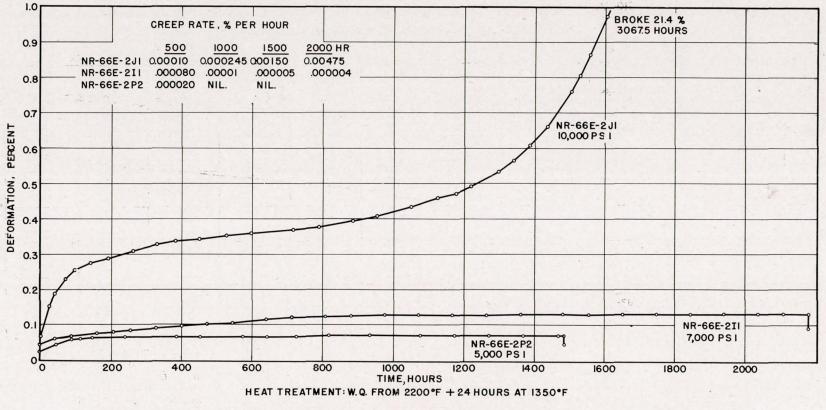
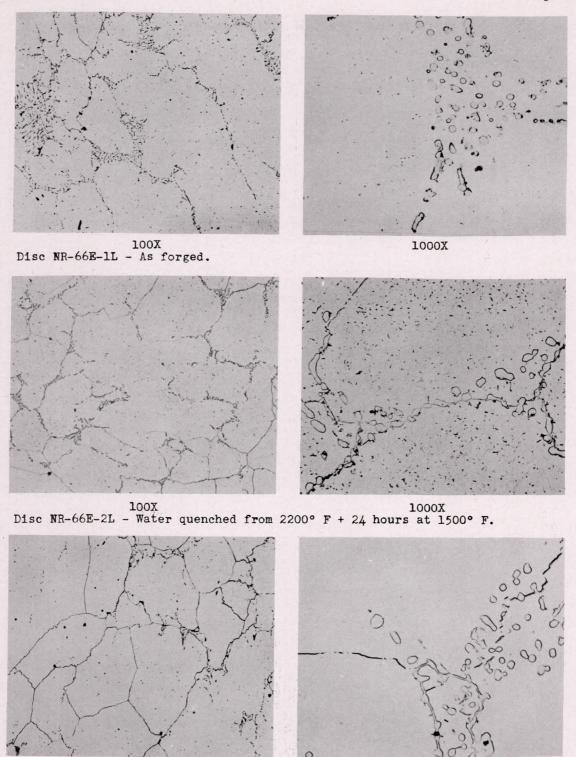


FIGURE 25.-TIME-DEFORMATION CURVES AT 1500°F FOR LOW-CARBON N-155 ALLOY DISC, NR-66E-2R.

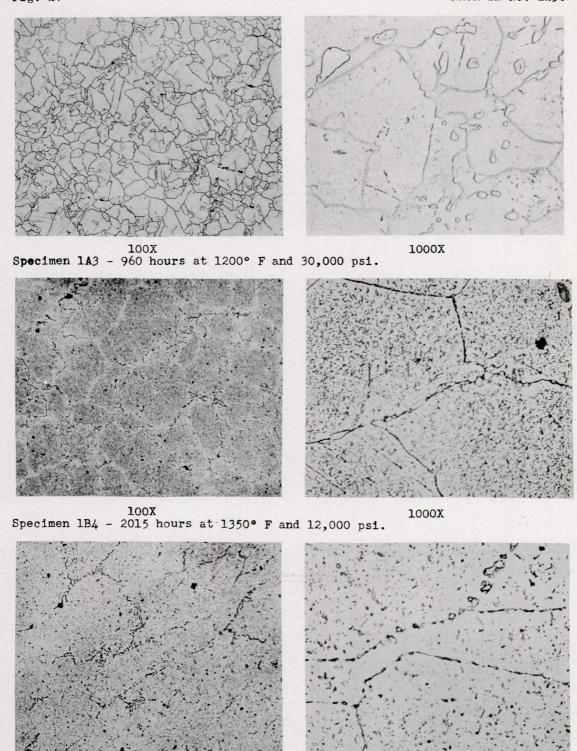
NACA TN No. 1230



 $$100\mbox{X}$$ Disc NR-66E-2R - Water quenched from 2200° F + 24 hours at 1350° F.

FIGURE 26.- ORIGINAL MICROSTRUCTURES FROM THE CENTER SECTIONS OF THE LOW-CARBON N-155 DISCS, NR-66E.

Fig. 27 NACA TN No. 1230



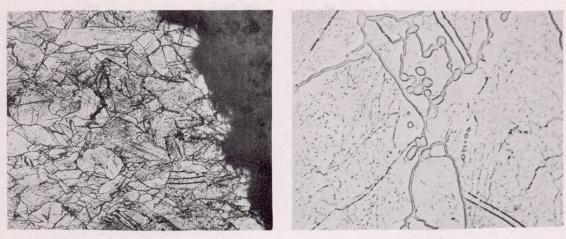
Specimen 1A1 - 2037 hours at 1500° F and 7000 psi.

Electrolytic chromic acid etch

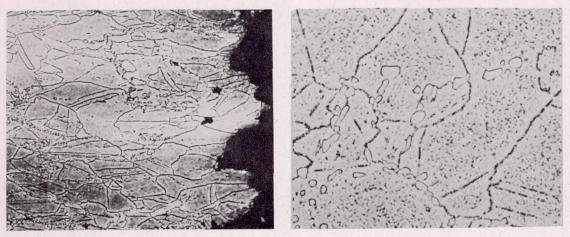
1000X

FIGURE 27.- MICROSTRUCTURE OF SPECIMENS FROM LOW-CARBON N-155 ALLOY DISC, NR-66E-1L, AFTER CREEP TESTS. TESTED AS FORGED.

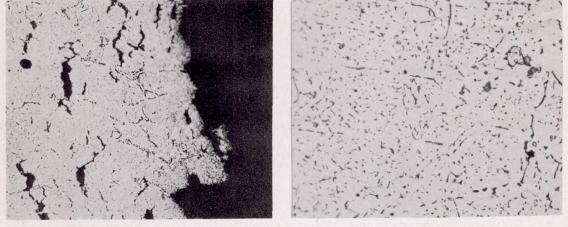
NACA TN No. 1230 Fig. 28



 $$100\mbox{X}$$ Specimen 1C5 - 613 hours for rupture at 1200° F and 40,000 psi.



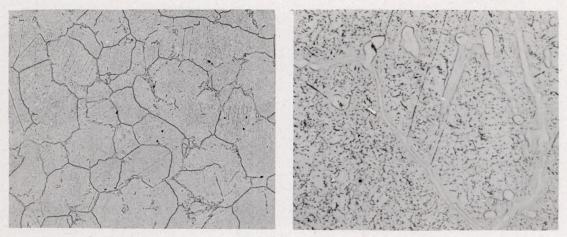
 $$100\mbox{X}$$ Specimen 1D4 - 624 hours for rupture at 1350° F and 21,500 psi.



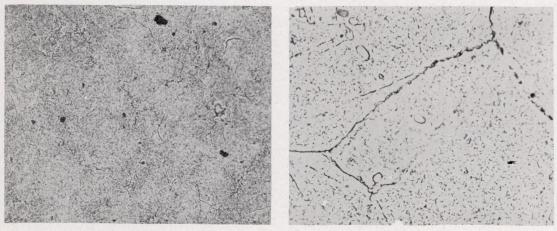
 $$100\mbox{X}$$ Specimen 1E4 - 449 hours for rupture at 1500° F and 14,000 psi.

FIGURE 28.- MICROSTRUCTURE OF SPECIMENS FROM LOW-CARBON N-155 ALLOY DISC, NR-66E-1L, AFTER STRESS-RUPTURE TESTS. TESTED AS FORGED.

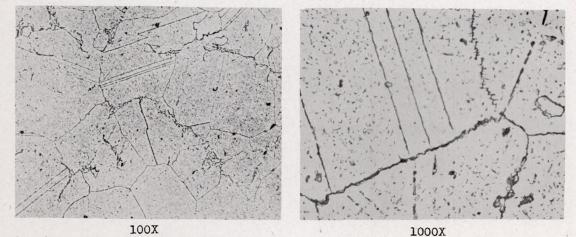
Fig. 29



100X Specimen 2A2 - 1078 hours at 1200° F and 25,000 psi. 1000X



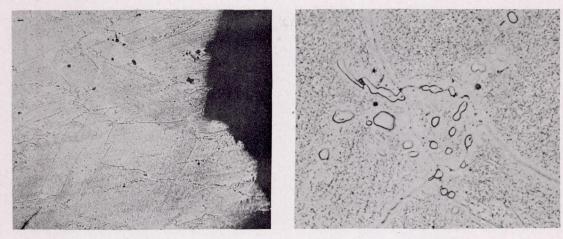
1000X Specimen 2B4 - 2016 hours at 1350° F and 12,000 psi.



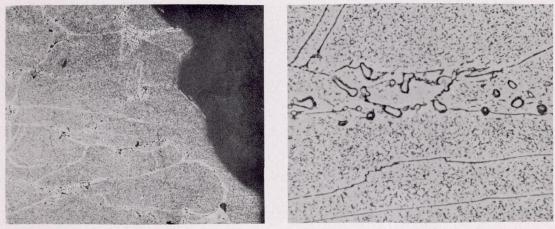
 $$100\mbox{X}$$ Specimen 2Al - 2775 hours at 1500° F and 7000 psi.

FIGURE 29.- MICROSTRUCTURE OF SPECIMENS FROM LOW-CARBON N-155 ALLOY DISC, NR-66E-2L, AFTER CREEP TESTS. WATER QUENCHED FROM 2200° F AND AGED 24 HOURS AT 1500° F.

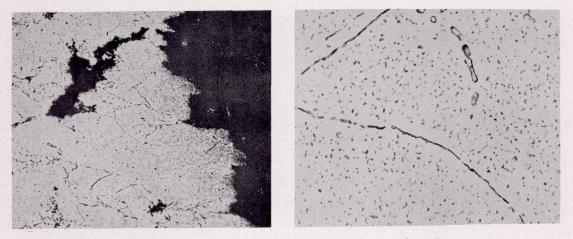
Fig. 30



 $$100\rm{X}$$ Specimen 2D4 - 1058 hours for rupture at 1200° F and 35,000 psi.

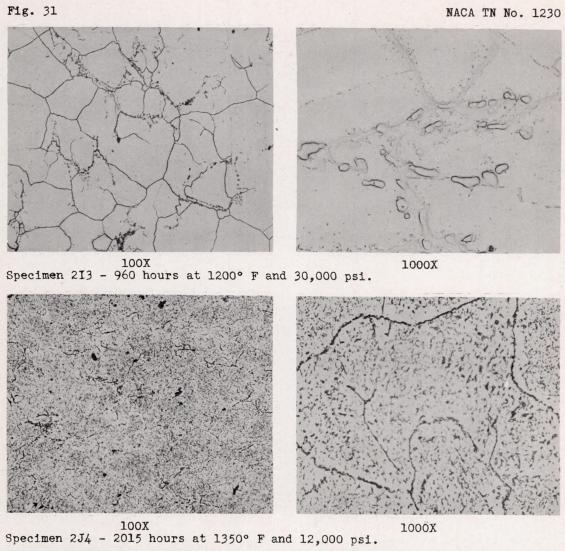


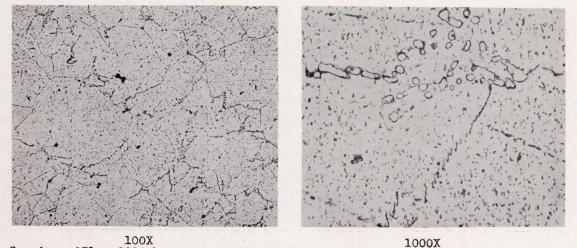
 $$100\mbox{X}$$ Specimen 204-2 - 729 hours for rupture at 1350° F and 21,500 psi.



100X Specimen 2E4 - 579 hours for rupture at 1500° F and 13,000 psi.

FIGURE 30.- MICROSTRUCTURE OF SPECIMENS FROM LOW-CARBON N-155 ALLOY DISC, NR-66E-2L, AFTER STRESS-RUPTURE TESTS. WATER QUENCHED FROM 2200° F AND AGED 24 HOURS AT 1500° F.

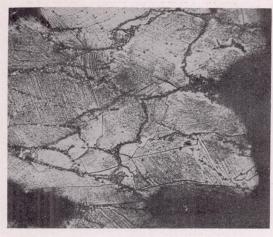


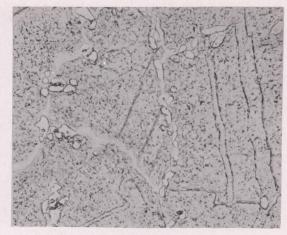


100X Specimen 2I1 - 2204 hours at 1500° F and 7000 psi.

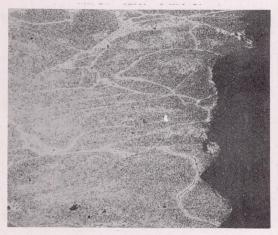
FIGURE 31.- MICROSTRUCTURE OF SPECIMENS FROM LOW-CARBON N-155 ALLOY DISC, NR-66E-2R, AFTER CREEP TESTS. WATER QUENCHED FROM 2200° F AND AGED 24 HOURS AT 1350° F.

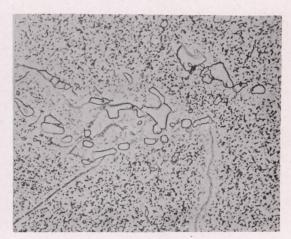
NACA TN No. 1230 Fig. 32



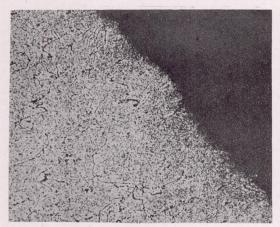


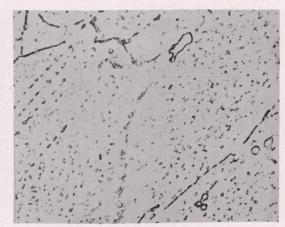
 $$100\rm{X}$$ Specimen 2K5 - 1536 hours for rupture at 1200° F and 35,000 psi.





 $$100\mbox{X}$$ Specimen 2L4-2 - 1068 hours for rupture at 1350° F and 23,000 psi.





1000X Specimen 2N1 - 485 hours for rupture at 1500° F and 15,000 psi.

FIGURE 32.- MICROSTRUCTURE OF SPECIMENS OF LOW-CARBON N-155 ALLOY DISC, NR-66E-2R, AFTER STRESS-RUPTURE TESTS. WATER QUENCHED FROM 2200° F AND AGED 24 HOURS AT 1350° F.

